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Prediction of Tropical Cyclone Formation in the Western Pacific Using Operational Global Models

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PREDICTION OF TROPICAL CYCLONE FORMATION IN THE WESTERN NORTH PACIFIC USING OPERATIONAL GLOBAL MODELS

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1. INTRODUCTION

Recent increases in the skill of tropical cyclone track predictions have been attributed to increased accuracy of guidance from operational global models. As this skill increases, dynamical prediction has been extended into the medium ranges, and five-day track predictions are becoming more feasible. However, as a tropical cyclone can form, intensify, and move over long distances in that time, the need for accurate numerical representation of tropical cyclone formation becomes significant.

A key feature of the success of the systematic approach to tropical cyclone track forecasting is the ability to recognize likely errors associated with specific dynamical models (Carr et al. 2001). Model error traits were identified after assessing the skill associated with an exhaustive set of dynamical model forecasts. The current study is an extension of the systematic approach to forecasts of tropical cyclogenesis via the identification of model error characteristics associated with forecasts of tropical cyclone formation. A primary objective is to examine successful and failed model predictions of developing and non-developing circulations and identify characteristics that distinguish the conditions represented in the model fields that correspond to a correct prediction of tropical cyclone formation.

2. METHOD

An algorithm has been developed to detect and track circulations in dynamical models. The detection of circulation centers in model analysis and forecast fields is based on the existence of a closed 850 mb relative vorticity contour with a magnitude of at least 1.5×10^{-5} s^{-1}. For this study, one-degree latitude/longitude fields from the Navy Operational Global Atmospheric Prediction System (NOGAPS) are used. To identify the circulation and various physical characteristics associated with the circulation, a multivariate normal probability distribution is used to fit an ellipse to the vorticity field.

A recent study by DeMaria et al. (2001) assessed the potential of tropical cyclone formation in the Atlantic using five-day averages of three environmental factors. While the background values of these factors vary by ocean basin (McBride 1981), it is possible to extend this genesis parameter to the western North Pacific. In the current study, a set of environmental parameters (Table 1) is defined relative to the elliptical representation of the circulation. The potential for tropical cyclone formation can be assessed relative to the various environmental factors defined for developing and non-developing circulations.

Table 1. Model parameters defined for every circulation center that meets the tracking criterion.

850 mb relative vorticity (10^{-5} s^{-1})
Shallow layer vertical wind shear (500 – 850 mb) (m s^{-1})
Deep layer vertical wind shear (200 – 850 mb) (m s^{-1})
Geopotential height thickness (200 – 1000 mb) (gpm)
Upper level (200 mb) warm anomaly (K)
Surface latent heat flux (W m^{-2})
Total (convective plus grid scale) precipitation (kg m^{-2})
Vertical motion (Pa s^{-1})
Vapor pressure (500 – 700 mb average) (Pa)
Sea-level pressure (SLP) (mb)
925 mb wind speed (m s^{-1})
700 mb wind speed (m s^{-1})
500 mb wind speed (m s^{-1})

3. EXAMPLE

Circulation and environmental characteristics have been identified for all western North Pacific vorticity centers that satisfied the duration criterion between 1 May and 31 October 2002. Although a large set of environmental characteristics can be defined from the elliptical representation of each analyzed and forecast circulation center, the example below highlights only 850 mb relative vorticity.

During the analysis process, vorticity circulations were separated into two categories: developers and non-developers. Developing circulations are defined as those numbered and warned on by the Joint Typhoon Warning Center (JTWC). Twenty-three of 24 storms warned on during the study period are included in this dataset. Two different formation times were calculated for each of the developing vortices. The first formation time for each storm, F_0, represents the time the first warning was issued by the JTWC. The second formation time, F^*_0, represents the first time in the Best-Track file, as determined by the JTWC during post-storm analysis. Non-developing vortices include 104 analyzed

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circulations tracked using the ellipse method that existed in the analyzed fields for at least 24 consecutive hours and did not develop to tropical depression strength. The base time used for the non-developing vortices, N_0, represents the time of the maximum analyzed 850 mb relative vorticity.

The figures below are summaries of the average analyzed and forecast 850 mb relative vorticity values centered on F_0 (Fig. 1), and F^*_0 (Fig. 2) for the developing circulations, and N_0 (Fig. 3). Each line represents a single model forecast time (i.e., the '+96' line represents only 96-hour forecasts). The forecast curves are defined from all forecasts that verified at the time on the x-axis relative to F_0 (Fig. 1), and F^*_0 (Fig. 2). The thin solid line on Fig. 1 is the average analyzed 850 mb vorticity value (5.0 x 10^{-5} s^{-1}) at F_0. The thin dashed line in Fig. 2 is the average analyzed 850 mb relative vorticity value (4.27 x 10^{-5} s^{-1}) at F^*_0. The dotted line in Fig. 3 is the average analyzed 850 mb relative vorticity value (3.34 x 10^{-5} s^{-1}) at N_0.

Various physical characteristics associated with circulations that developed to at least tropical depression strength can be examined from the extensive datasets captured with the elliptical representation of each circulation center. Forecasts associated with circulations that failed to reach warning status (non-developers) may be examined to identify characteristic traits associated with NOGAPS predictions of circulation development.

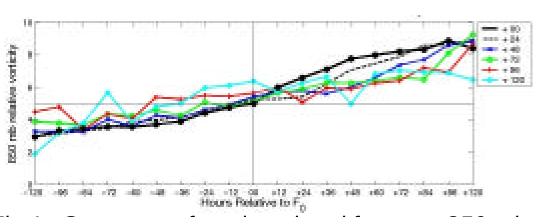

Fig 1. Summary of analyzed and forecast 850 mb relative vorticity (x 10^{-5} s^{-1}) for all developing vortices relative to the first warning time (F_0).

The average forecast 850 mb relative vorticity for the developing circulations was consistently greater than the analyzed 850 mb relative vorticity prior to and at F_0 (Fig.1). After F_0 the vorticity is under-forecast compared to the analyzed values. This distinct change in the 12 hours following F_0 may be due to the inclusion of synthetic observations in the NOGAPS analysis in the first model integration after F_0. Also, larger errors in forecast vorticity occur with increased forecast range in both Fig.1 and Fig. 2.

For developing circulations the average timing difference between F_0 and F^*_0 was 28.4 hours. This is evident in Fig. 2, where the transition from over- to under-forecasts of vorticity occurs between 24 and 36 hours after F^*_0. The over-development of developing vortices is also evident in Fig. 2 as NOGAPS over-forecasts relative vorticity prior to the addition of synthetic observations (at approximately F^*_0 + 36 hours), and then under-forecasts relative vorticity after that.

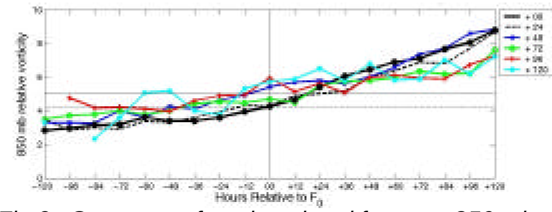

Fig 2. Summary of analyzed and forecast 850 mb relative vorticity y(x 10^{-5} s^{-1}) for all developing vortices relative to the first Best-Track time (F^*_0).

The tendency of NOGAPS to over-develop non-developing circulations after the maximum vorticity is reached is evident in Fig. 3. As the forecast range increases, the maximum forecast vorticity value is reached farther after N_0.

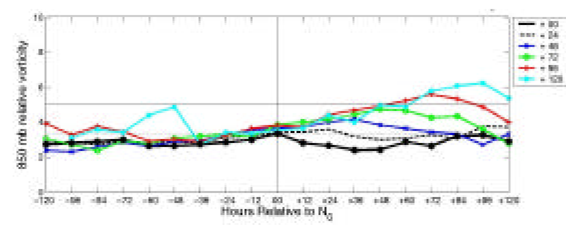

Fig 3. Summary of analyzed and forecast 850 mb relative vorticity (x 10^{-5} s^{-1}) for all non-developing vortices relative to the time of maximum analyzed vorticity (N_0).

In addition to the analysis of developing and non-developing vortices, circulations that existed for less than 24 consecutive hours, but were forecast to exist for more than 24 hours are analyzed separately. Finally, forecast vortices that never verified are categorized as false alarms. Summaries of these categories will be presented.

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